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ARTIFICIAL EARTH SATELLITES INVESTIGATE THE ENVIRONMENT

Yu. V. Zonov

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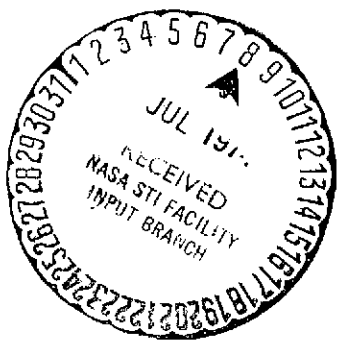

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ARTIFICIAL EARTH SATELLITES INVESTIGATE THE ENVIRONMENT

Yu. V. Zonov

Yuriy Vasil'evich Zonov, Head of the Scientific Information Division of the Institute of Space Research of the Academy of Sciences of the U.S.S.R., is occupied with problems of disseminating and use of information from outer space about natural resources.

Mankind Has Perceived a Danger

The creation of material wealth is not the only thing associated with man's productive activity. /2* The growth in the scale of production gives rise to a corresponding increase in the quantity of harmful wastes discarded in the environment. Notwithstanding the development of new technological methods intended for reducing industrial wastes, and the establishment of expensive purification facilities, the increase in the quantity of wastes accompanying the vigorous growth in industrial production on the earth nevertheless exceeds in total volume what has resulted from progress in the struggle for a clean environment.

Industrial wastes are the most serious and basic part of the multidimensional problem of pollution of nature.[1] There has appeared quite recently the term "esthetic pollution" to denote

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*Numbers in the margins indicate pagination in the foreign text.

[1]See: The selection of articles "For Preserving Nature; For the Efficient Use of Natural Resources". Priroda, 1973, No. 1.

a deterioration in esthetic quality in man's surroundings, a lessening of the regions where man comes into contact with nature, and of the rest areas. Even noise belongs among the polluting factors.

Concern for preserving a clean environment has been expressed in a whole series of measures undertaken by governments of various countries on both the national and on the international level.[2]

The resolution recently passed by the Central Committee of the Communist Party of the U.S.S.R. and by the Council of Ministers of the U.S.S.R., "To Strengthen Preservation of Nature and Improve the Use of Natural Resources,"[3] demonstrates how great is the value attached to the problems of protecting living nature and the struggle for a clean environment in our country. Although pollution of the natural environment has not reached the catastrophic level in our country which is characteristic of the industrialized countries of America, Europe, and Asia, the Party and government are taking decisive steps to keep nature and, thereby, man from being harmed. Here are pertinent decisions for rational use and conservation of the natural systems of Lake Baykal, for protecting the basins of the Volga and Ural Rivers against pollution, together with a number of other decisions.

At the same time there is much to do if we are to be certain that nature, in spite of the harm done to it, preserves its regenerative capacity.

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[2]See: A. I. Bannikov. "International Cooperation in the Matter of Protecting the Environment." Priroda, 1973, No. 1, page 79.

[3]Pravda, January 10, 1973.

Dissipation and Migration of Pollutants

The basic sources of pollutants usually bear a 'point' character, and the district of emission of polluting agents is sufficiently limited. This pertains not only to industrial sources, but also to natural sources-- and peat fires, volcanic eruptions, etc. The problem of environmental pollution, in fact, appears where the dissipation of polluting agents, thanks to nature's normal processes, is insufficient for sustaining their concentration below some level at which the possibility for self-cleaning is preserved. If the concentration of polluting agents exceeds this limit the natural processes are disturbed and irreversible changes occur.

In order to control the disposal of waste products it is above all necessary to study their interaction with the environment, i.e., the change of their physical and chemical properties, the dynamics of their movements across the terrestrial globe, etc.[4] Therefore, the processes of dissipation must be considered in conjunction with processes of migration which can lead to a build-up of pollutants in regions far from the sources. However, using only ground methods for observations, it is difficult to follow both processes: for this, one needs either a large number of ground stations for gathering data or mobile laboratories conducting numerous measurements. The cost of such a data gathering system is extraordinarily high. The situation suggests the case of a man in a forest who must learn its area and circumference. He can either traverse the entire forest, or climb a mountain and at once perceive its size and shape. Only in this case the problem is simpler, inasmuch as a forest is static, while the area in which pollutants spread can vary depending on the set of natural phenomena.

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[4] See, in addition: M. Strong, V. N. Kunin. "The Natural Environment--A Single Whole." Priroda, 1973, No. 5.

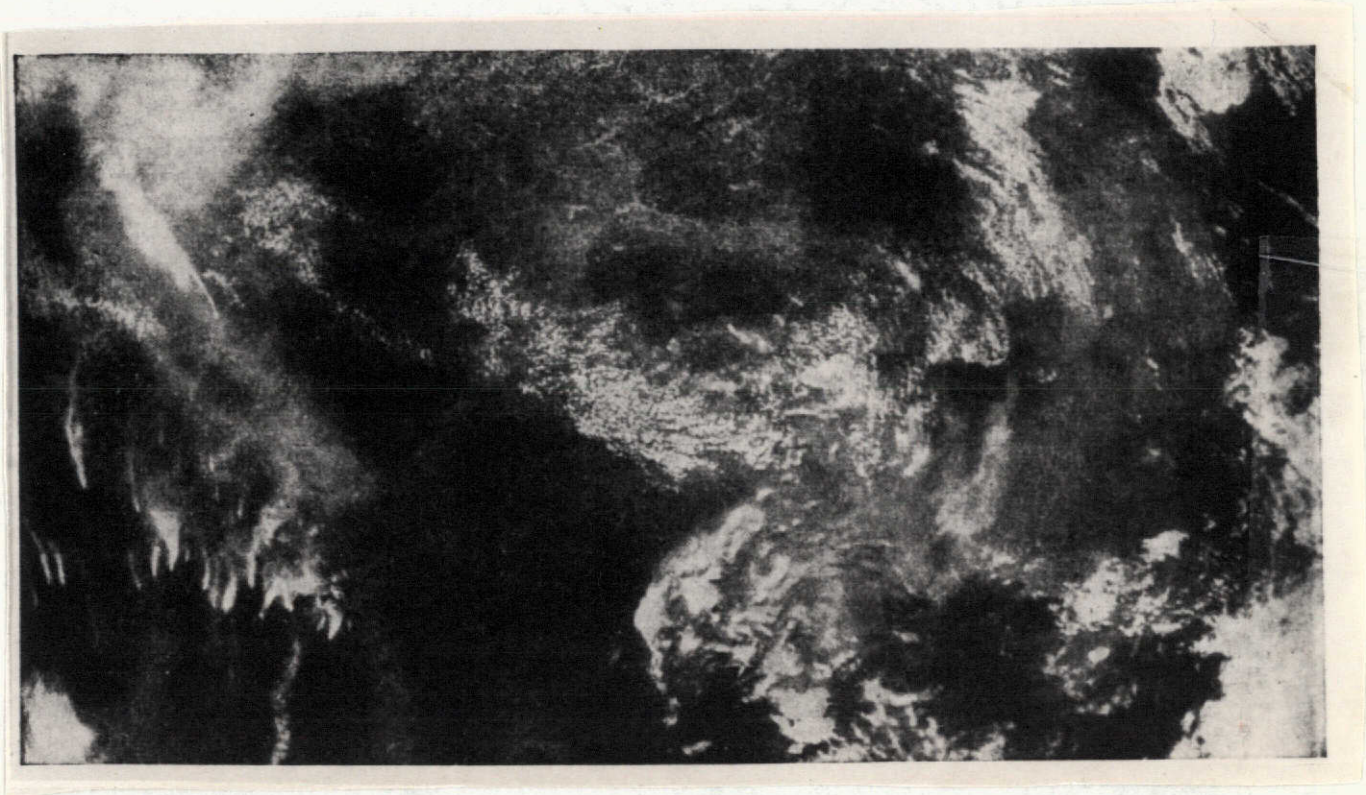

Fig. 1. Smoke from forest fires photographed by the television system of the Meteor-10 Soviet meteorological satellite, July 13, 1972. It is evident that the plumes of smoke behave in various ways: in some regions the smoke intermingles with the turbulent atmosphere and disperses for great distances; in other regions, where the air currents are quiescent, the smoke extends in one direction; in a windless zone the smoke can be localized for a long period of time. Detailed photographs allow us to determine the regions where conditions for the onset of persistent air pollution can accumulate.

Artificial earth satellites (AES) can render great assistance for studying the processes in the spread of industrial wastes in nature and, in addition, for achieving working inspections for complying with established norms.

The Possible Role of Satellites

Recently the possibility of using artificial earth satellites for studying the environment and for detecting natural resources has been investigated. Satellites equipped with special instrumentation for observing the earth's surface and the processes occurring on it allow us to generate, and repeatedly perform, panoramic surveys of the earth's surface in the space of a small time interval and to guarantee a fast and sometimes instantaneous transmission of a picture of the observed phenomena to the data gathering center. Researches conducted aboard a series of Soviet spaceships and manned spacecraft, including the Soyuz-type spacecraft and the Salyut space stations, provided a wealth of material on the basis of which new methods were developed for studying the environment and the earth's natural resources. In the U.S.A., too, similar investigations were carried out. The Earth Resources /4 Technology Satellite (ERTS-1) launched there in July 1972 was intended particularly for perfecting the technique and research methods for investigating the earth's natural resources from outer space. A broad program of observations is being carried out from on board the Skylab space station.

Plumes and condensations of fumes emitted by factory and plant chimneys show up extremely clearly in photographs taken from space. By studying the direction and behavior of a plume of smoke one can establish the direction and dynamics of the air currents and determine the degree of local turbulence and the rate of mixing and dissipation of the smoke in the atmosphere. By means of special instruments installed on the spacecraft it is possible to determine the density and composition of the fumes and, thereby, to ascertain whether or not the exhaust exceeds permissible levels, and whether there exists a danger of pollution. Smoke from forest fires shows up very well in photographs from outer space. (FIG. 1)

Fig. 2. The estuary of the Colorado River. Photograph taken by Apollo-9 in infrared light. The carrying out of solid wastes by the river into the Gulf of California can be easily seen. The photograph demonstrates the feasibility of using artificial earth satellites for studying pollution of the world ocean.

Some of the gases emitted into the atmosphere by industrial plants are invisible to the naked eye, yet they are nevertheless highly toxic. For example, sulfur dioxide which results from burning coal with a high sulfur content in municipal heat and electric power plant furnaces is invisible, yet highly toxic. Nevertheless, instruments exist (for example, correlation spectrometers) which can distinguish it from a distance and determine its concentration and distribution. The feasibility of mounting these devices on artificial earth satellies is currently under study.

The likelihood of detecting, by means of lasers, certain gases which are polluting the atmosphere should not be excluded. Such gases as oxide and nitrogen peroxide can be detected by measuring the Raman scattering of radiation from the radioactive lasers located onboard satellites.[5] Another method consists of locating calibrated sources of monochromatic light in regions where there exists a danger of atmospheric pollution. Absorbtion of atmosphere fluxes from these sources is measured by the satellite's receivers, and the presence and concentration of the different gases are determined according to these measurements.

It seems that one may expect devices and methods to be created in the future by means of which it will be possible to accurately control the presence and spread of harmful industrial gases, and, on the basis of this data, to make corresponding decisions on locating heat and electric power plants, changing from one kind of fuel to another, and other necessary measures.

Artificial earth satellites also allow us to investigate such phenomena as the smog associated with large industrial centers[6].

Finally, satellites can be of significant value for solving

[5]See: V. Ye. Zuyev. "Laser Probing of the Atmosphere." Priroda, 1972, No. 10.

[6]See: M. T. Dmitriyev. "Photochemical Smog". Priroda, 1971, No. 2

one of the most critical problems -- the problem of pollution of the world ocean. Let us discuss this problem in some detail.

The Pollution of Reservoirs

In many countries a shortage of fresh water is strongly felt. This does not mean, however, that all its sources are exhausted. The majority, not only of surface, but often of underground sources, are so polluted that the water in them is unfit /5
for use without a most complex preliminary purification. Industry which uses this water for disposal of wastes into the "boundless ocean" is guilty to an enormous degree. However, during a prolonged trip to the ocean some of the water seeps into the soil and many polluting substances get into underground water reserves. Many cases of biological pollution of reservoirs have been detected, in addition to pollution by chemical agents. For example, because of sewage effluents the quantity of bacteria in the St. John River (State of Florida, U.S.A.) is twenty-eight times greater than the level assumed safe for bathing.

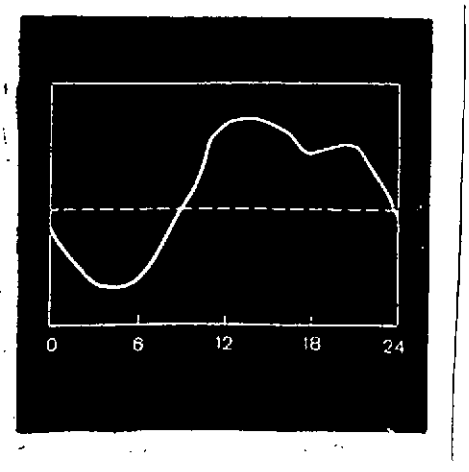

Fig. 3. Typical graph of the variation in the magnitude of the disposal of domestic waste waters during a day in relative units (according to data in the report of P. A. Castruchcho et al. (U.S.A.) at the XXIII Congress of the International Astronautical Federation, Vienna, 1972).

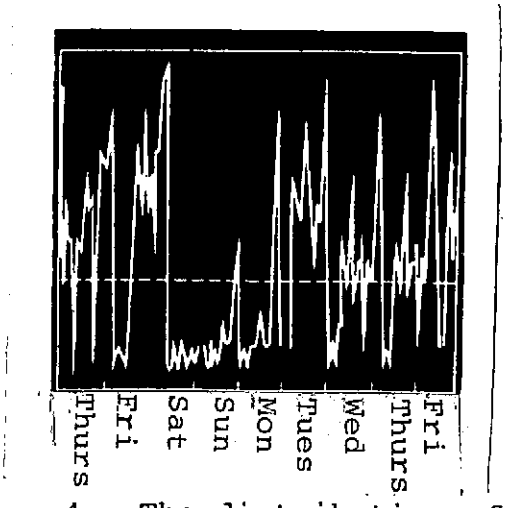

Fig. 4. The distribution of the drainage of industrial wastes by days of the week in relative units (according to data from the same report, see Fig. 3).

Thermal pollution of rivers and coastal areas of seas and oceans appearing in association with the disposal of hot waters from heat and electric power plants and from other industrial plants represents a serious problem in recent years. Thermal pollution leads to changes in the biological cycle of reservoirs, destruction of beneficial forms of sea organisms, and to an excessively intense growth of certain kinds of seaweed.

The disposal of wastes into the world ocean not only does not solve the problems of these very wastes, but causes colossal damage to sea productivity. Wastes first settle onto the continental shelf (Fig. 2) precisely where basic life in the ocean is concentrated and where almost 50% of the world's fish yield is caught. Ten of the most densely populated industrial areas of the world are located in direct proximity to the ocean, where they dump all their wastes: New York, London, Tokyo, Bombay, Buenos Aires, Shanghai, Calcutta, Osaka, Los Angeles, and Philadelphia. Moreover, these cities, and, in addition, many other industrialized regions of the world, are linked with river estuaries and sea inlets. At the present time these zones prove to be especially polluted. The processes of natural biological purification do not keep up with increasing pollution. However, calculations show that even there, where pollution of inlets and estuaries of rivers has not reached a very high level, the volume of incoming wastes can be neutralized by the natural mechanisms of purification. Where then lies the problem? In the fact that wastes are not entering uniformly and that not all the possibilities for natural purification processes are being utilized for their natural recovery.

In Fig. 3 a typical recording is depicted of the flow of domestic wastes during one day and in Fig. 4 a recording of the flow of industrial wastes during the week. It is evident that the flows are highly nonuniform.

Apart from the nonuniformity of the inflow, the flow of wastes is characterized by a highly diverse composition. Here is a list of the basic constituents of the wastes which accumulate in river estuaries and sea inlets: floating wastes (garbage, petroleum products, oils), solid suspensions, pathogenic bacteria, chloride compounds, acids, alkalis, phenols, toxic substances (mercury, cadmium, cyanide compounds), farm manure, radioactive substances, an increased salt content, et al. The list grows from year to year.

Counteracting Wastes Contained in Water

Oxygen plays a major role in natural purification of water. Bacteria and algae utilizing the oxygen contained in water digest organic wastes into neutral components. If the content of oxygen is insufficient, an anaerobic process which does not require oxygen goes into action, but then organic substances decompose extraordinarily slowly. In the chemical process, radioactive, inorganic and potentially dangerous substances are digested into harmless forms. Oxygen is also required for the chemical process, although not in such quantities as for the biochemical process.

The quantity of oxygen and its distribution in water depend on a set of interacting factors: the water temperature, the mixing rate, good contact with the atmosphere, and other factors. If there is petroleum or oil film on the surface, the intake of oxygen from the atmosphere is sharply reduced. With poor agitation, the process yields its place to a much slower anaerobic recovery process, during which, in addition, foul-smelling gases are given off. An increase in the water temperature due to the disposal of thermal wastes also leads to a reduction in the solubility of oxygen in the water. At the present time, data obtained from satellites show that the temperature of water in the estuaries of great rivers is higher by several degrees than the water in neighboring regions of the sea.

It is possible to say that, to a significant degree, the problem of pollution of coastal waters can be solved if each /6
molecule of the wastes combines with a sufficient quantity of oxygen. Meanwhile, however, mankind has learned how to do this only in very small volumes, and in the conditions of river estuaries and sea inlets we are obliged to rely on the natural processes of mixing, dispersion, and aeration of water. The problem of optimal usage of these purification processes is an extremely difficult one and has not yet been solved. At the same time, regulating the flow of wastes, disposing of these wastes in suitable places, controlling coastal currents by means of dikes, and using other measures makes it possible to use the natural processes of treatment and dispersion of wastes more efficiently. For this it is first necessary to determine those hydrodynamic processes which take place in inlets and river estuaries. One of the methods for solving this problem consists in constructing physical and mathematical models.

Models of Inlets and River Estuaries

Physical models, although convenient, require long-term and detailed adjustments for the object being investigated and are extremely expensive. Thus a model of the Hudson River, along which New York City is located, costs about $150,000, and its maintenance comes to another $150,000 per year. These physical models are unique; that is, for each object, a separate model must be constructed.

Mathematical models have, in comparison with physical models, such advantages as being more flexible, allowing for variations in the conditions of the problem, permitting the results to be obtained quickly, and being comparatively inexpensive.

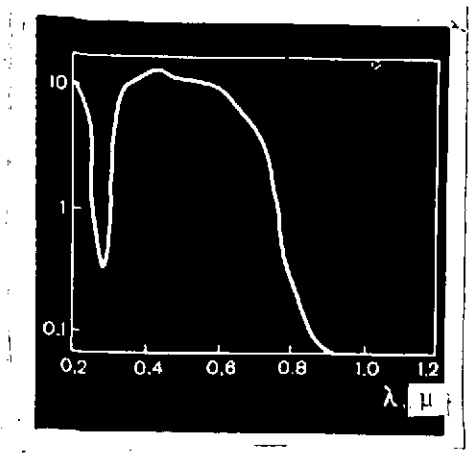

Fig. 5. The reflection spectrum of pure distilled water. It is evident that in the near infrared region water practically does not reflect incident light; consequently, in photographs of reservoirs taken in infrared light, portions of pure water appear to be of deep color, while polluted water, is of various color tones depending on the nature of the pollutant. The wavelength λ is represented along the abscissa axis, and the logarithmic rate of reflection in relative units along the ordinate axis.

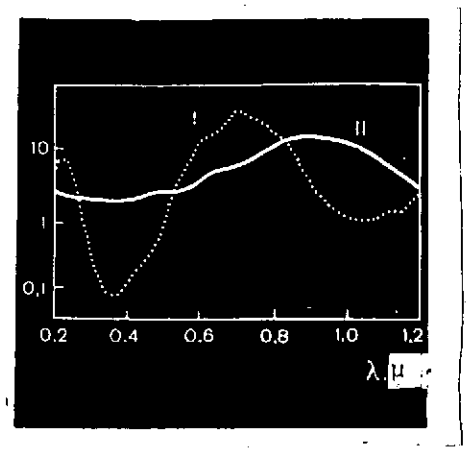

Fig. 6. The reflection spectrum of liquid sulfite suspensions (I) and of wastes from a steel mill. It is evident that in the infrared regions these substances reflect light; consequently, in photographs taken in infrared light, portions of the water containing these pollutants appear to be luminous. The wavelength λ is represented along the abscissa axis, and the logarithmic rate of intensity of reflection in relative units along the ordinate axis.

Mathematical models of bays or river estuaries represent a formulation in mathematical terms of the relations and interactions between the hydrodynamics of the bay and the internal forces. If these relations are expressed in an accurate fashion, no matter now complex, and if one accurately measures the actuating forces of the internal environment, then mathematical models can be created with a high accuracy. However, the laws of motion of a liquid are complicated. The geometry and topography of a bay and the internal forces are difficult to measure and describe in mathematical terms. Consequently, all kinds of

simplifications must be introduced. But each simplifying condition must be correlated with actual measurements in order to clarify whether it results in such a deviation in the formulation of the model as to make the entire model too gross and inaccurate.

When investigating, for example, a sea inlet, one must measure the topographical parameters (geography of the inlet and the contour of the sea bed), the hydrodynamic parameters (magnitude and direction of the velocity vector of the current, diffusion coefficient along the current, at right angles, and along the vertical), the parameters of the water quality (pathogenic, chemical, and physical components), the acting external forces (wind, rainfall, surface conditions, content of suspensions, mixing with salt water, temperature). This list can be increased or decreased in correspondence with the complexity of the model.

As is evident, the volume of data to be fed into a model is extremely large, much greater than what nonunique observations and long-term series of measurements require. At the same time collecting the data is extremely difficult for a number of reasons. For example, a tracking station measuring the amount of water-soluble oxygen and temperature costs almost $20,000, its upkeep comes to $10,000 per year, and, moreover, a detector located in sea water often fails because of corrosion, encrustation with sea organisms, the physical action of waves, and accidental or deliberate damage.

It is here, then, that the unestimable advantages of artificial earth satellites are manifest.

Performing observations from a high altitude, a satellite encompasses a wide territory. A single instrument can make measurements in all observable districts, which provides a set of data for the entire region, doing away with the very complex problem of

calibration usually existing in the operation of systems of multiple detectors. Evidently, the expense of a single survey of /7 one or another parameter of the environment from a satellite will be substantially less than for the usual methods.

Thermal detectors located onboard a satellite can measure temperature with an accuracy of several tenths of one degree. The use of similar detectors in scanning systems allows us to obtain images in the thermal band of the spectrum and to observe the nature of water circulation, as a result of which it is possible to determine the hydrodynamic parameters at least in surface layers.

A photographic study of the state of portions of the dispersion of turbid water can serve as a basis for determining water currents and the nature of diffusion processes. Accurate measurements of the currents can be carried out by the method of stereoscopic photography, in which natural or artificial objects, or markers, are photographed over a given interval of time. Moreover, diffusion processes can be measured by observing the spread of patches of synthetic dyes such as rhodamine specially introduced in the water at the place required.

Independent experimental data show that pollutants such as petroleum derivatives, suspended sludge, certain toxic and solid wastes of the chemical industry, thermal wastes, and dissolved manure can be detected from on board satellites.

One of the first photographs obtained from the American ERTS-1 satellite encompassed the city of Boston and the bay adjacent to it. Speciallists examining this photography noticed that the pipes for discharging sewage into the sea were found in a spot from where all the wastes are carried by the current in the bay back to the city.

An observation in different portions of the spectrum provides researchers with a new and powerful method for detecting certain pollutants. In Fig. 5, for example, the reflection spectrum of pure distilled water, and in Fig. 6, the reflection spectra of a suspension of sulfite and wastes from steel mills in water, are presented. It is possible from these figures to draw the conclusion that, by observing the investigated region in the spectral region 0.8-1.2 μ, it is possible to obtain a picture in which pure water will have a deep, or practically deep, color, while polluted water appears clear.

The method of photographing objects in different portions of the spectrum was used for obtaining a photograph of the suburbs of Seattle (State of Washington, U.S.A.) from the ERTS-1 satellite together with the paper and pulp plants located nearby which dispose of wastes from their production into the inlet. This photograph, taken in bright conditions, is shown on the rear cover of the magazine.

The technique of creating similar photographs consists in the following. One and the same object is shot in several, usually three, regions of the spectrum; the black-white negatives obtained are exposed to light of different, and specially selected, colors, and then these pictures are superimposed. As a result, a color photograph is obtained very conveniently for quick visual identification of various kinds of objects. In this case, colors were selected such that vegetation appears colored in red; rocks, asphalt, and stone--grayish-blue. It is easy, knowing these conventions, to determine that in a bluish photograph areas of dense urban settlement are isolated where there are many stone buildings and asphalt; suburbs and farming areas where there are many different kinds of vegetation are tinted with a red color of various intensities; regions covered by a forest have a uniform bright red color. Snow on mountain peaks is distinguished by the

Fig. 7. The region around the city of Seattle (State of Washington, U.S.A.), photographed by the American ERTS-1 satellite. The pulp and paper factories located here pollute the inlet with wastes from their production: The polluted portions are distinguished from clean water (dark color) by a lighter tint. White in the photograph indicates asphalt, stone, and rocks; dark gray, zones of greenery.

color white. The small blue patch in the background of the black /8
water of the bay in the center of the photograph (an enhanced black-white contrast of this portion is presented in Fig. 7) is the trace of industrial wastes from pulp and paper plants. The different color of the water in lakes is a function of their depth and turbidity.

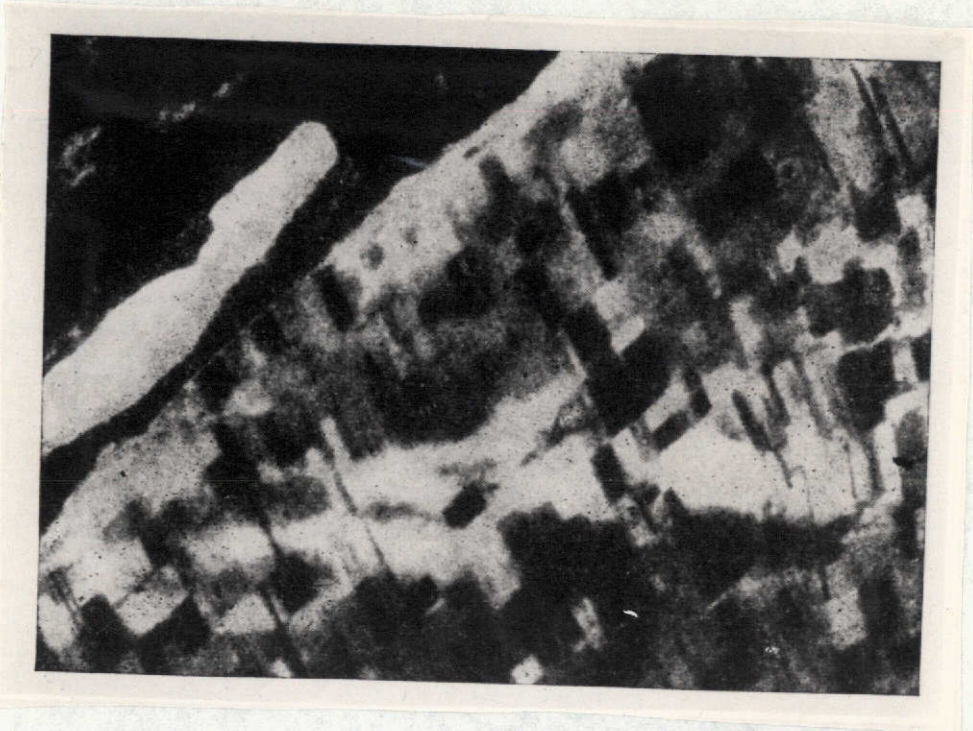

Fig. 8. A picture of the ground cover which was obtained by a camera mounted on the "Salyut" Soviet permanent orbiting station. Clear bands of eroded soil are seen in those portions with simpler mechanical composition (the clear white patch in the upper left part of the photograph is the sea surface illuminated by the sun).

It is possible, by photographing the plumes of pollutants by such a method, to determine the relative concentration of pollutants in water for an entire area and to utilize these data as input into a model that has been constructed. It is possible, by carrying out only a limited number of direct measurements of the extent of water pollution, to convert relative values into absolute values for various points of the area under consideration.

The use of an infrared technique for detecting thermal radiation promises to supply researchers with the means of observation and inspection and, in addition, for detecting thermal pollution of rivers and coastal regions of seas and oceans.

Recently investigative efforts have vigorously developed the use of super-high frequency methods for detecting oil films on the surface of seas and oceans. The results obtained are extremely encouraging.

It is easy, by carrying out a survey from satellites of bodies of water, to detect in photographs taken in infrared light places of vigorous growth of seaweed, since water in this region of the spectrum does not reflect, and the chlorophyll of seaweed reflects infrared light excellently. Biological pollution is detected by means of a correlation between the brightness of the tones and the granularity of the pictures in three regions of the spectrum--blue, green, and red. The brightness of polluted, in comparison to pure, water will be higher in the blue and infrared regions of the spectrum and lower in the green region.

Erosion and salinization of soil appearing when violating the regulations for its agricultural cultivation, the use of lands under tailings from slag and from garbage dumps, and open-pit mining of useful minerals belong among the factors which are destructive to and which impair the environment. It is possible here to refer also to overgrowth of fellings with low-value kinds of timber and the destruction of the ground cover of mountainsides when improperly cutting down a forest. All these phenomena can be easily scanned in photographs taken from outer space, since they can be rapidly studied and the damage inflicted by them sufficiently accurately estimated.

The Creation of a World Monitoring System

Th problem of the conservation of nature cannot be solved by the powers of one, or within the boundaries of one, government. Reports have repeatedly appeared in the press that industrial pollution destroys vegetation and the animal world at a distance

of hundreds of kilometers from the sources of the pollution situated in other countries. One such report described the destruction of forests in Sweden from industrial gases carried by winds from the Federal Republic of Germany, where upwards of 20 million tons of harmful substances are emitted each year into the atmosphere.

The sadly well-known fate of the Rhine reflects emerging international problems, when the water of a river comes from one country (Federal Republic of Germany) into the boundary of another (in this case, the Netherlands), being contaminated and therefore completely unfit to use.

According to data from investigations[7] nearly 2 million tons of petroleum and petroleum by-products are dumped each year from tankers and leak from offshore oil wells and from other sources directly linked to the sea into the global ocean. Moreover, nearly 9 million tons of petroleum by-products get into the global ocean from the atmosphere where they accumulate due to incomplete combustion of petroleum by-products in automobile engines, furnaces of industrial plants, domestic heating systems, et al. If it is possible /9 in the first case to find the source of pollution, then in the second case, which is the more serious case, it is simply impossible to determine the actual sources of pollution--the entire civilized world appears to be the polluter.

Well then, the problem of determining the source of pollution is very important. It is not enough to merely set permissible levels and regulations for the dumping of industrial wastes; we must establish control for their fulfillment. Since pollution has a tendency to migrate and spreads over the

[7] B. Lundholm, "The Use of Earth Survey Satellites in Monitoring the Changes in the Global Environment." U.N. Report: A/AC/.105/C.1/VIII/CRP.1, March 8, 1971.

entire terrestrial globe, a world monitoring service is necessary which must be located not only in areas of the sources of pollution, but also in the most remote points of earth, such as the Arctic and the Antarctic.

The question of creating a world monitoring system for the environment has already been discussed over a period of a number of years.

The upkeep of a network of monitoring stations covering the entire world and maintained by a large number of workers is extraordinarily costly. A switchover to using automatic independent stations which collect various data on the environment and which transmit the data to special information collection centers is significantly more efficient. However, a problem emerges here for automatically transmitting the data collected by radio over many hundreds, and often, over thousands of kilometers. In order to maintain the reliability of reception we need to set up powerful receivers and correspondingly large power sources, which leads to an increased cost of the entire system and greater complexity of the system.

Satellites can render positive assistance here. A satellite traveling at a height of several hundred kilometers over automatic stations sends a command to them to transmit the data collected, records these data and subsequently transmits it to the information collection center. Thus, a satellite can, over a short period of time, query all the stations located in deserts, on buoys on the oceans, in inaccessible mountain regions, and elsewhere.

At the present time the opinion is held by specialists that the use of satellites for solving the problems of pollution of the natural environment can prove to be sufficiently fruitful. Further development of instruments and methods for monitoring from outer space, together with the evolution of social and

technical systems for preserving the environment, will assuredly lead to the development of new possibilities for applying space methodology for preserving nature.